Title

Influence of Femoral and Tibial Deformities on Postoperative Alignment after Opening Wedge High Tibial Osteotomy

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Abstract

Background: Opening wedge high tibial osteotomy (OWHTO) is a surgical procedure for treatment of varus malalignment due to medial compartment knee osteoarthritis. This study was performed to analyze the relationship between axial parameters of lower limb alignment and the degree of undercorrection or overcorrection after OWHTO.

Methods: We retrospectively evaluated 45 patients (45 knees) who underwent OWHTO. The percentile of the mechanical axis on the tibial plateau at 12 months postoperatively was divided into three groups (undercorrection, acceptable correction, and overcorrection), and five parameters of axial lower limb alignment [mechanical lateral distal femoral angle (mLDFA), lateral bowing angle of the femoral shaft (BFS), femoral neck–femoral shaft angle (FNFSA), and preoperative and postoperative mechanical medial proximal tibial angle (mMPTA)] were statistically analyzed among the three groups.

Results: Undercorrection was found in 12 (27%) patients, and overcorrection was found in 10 (22%) patients. The mLDFA and BFS were significantly associated with undercorrection. Moreover, the postoperative mMPTA was significantly associated with overcorrection.

Conclusions: Unacceptable correction after OWHTO was associated with femoral deformity and postoperative mMPTA. To prevent postoperative undercorrection, if the preoperative mLDFA exceeds 90.0° and the BFS exceeds 0.35°, the patient may have not only an indication for OWHTO but also an indication for double level osteotomy.

Key words: Knee osteoarthritis, Open wedge high tibial osteotomy, Femoral deformity, Lateral femoral bowing, Tibial deformity

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Introduction

Opening wedge high tibial osteotomy (OWHTO) transfers the weight-bearing load axis from an affected medial compartment to a relatively intact lateral compartment with the aim of improving symptoms and postponing or avoiding arthroplasty[1)2)]. Maintenance of the targeted weight-bearing load axis after correction is reportedly important to achieve a good clinical outcome[3)-5)]. Whereas, undercorrection may cause the poor clinical outcome[6)7)], and overcorrection can lead to the poor clinical outcome and to tilting of the joint line, which is often difficult to treat with an arthroplasty[8)9)]. Several reports have described cases in which the weight-bearing load axis did not achieve an accurate targeted weight-bearing load line even after the correction was performed based on preoperative planning and intraoperative confirmation[7)10)]. Additionally, a study evaluating the effect of the geometric features of the femur and tibia suggested that the inclinations of the distal femoral condyle and proximal tibial condyle were associated with malalignment after OWHTO[11)]. Osteotomies around the knee with consideration of the knee joint inclination were recently reported to be efficient in patients with huge varus deformities involving the femur and tibia[12)13)]. Deformities of the femur include abnormalities of the femoral neck–femoral shaft angle (FNFSA) in the proximal femur, lateral bowing angle of the femoral shaft (BFS) in the metaphysis of the femur, and inclination of the femoral condyle in the distal femur[14]. However, the influence of femoral and tibial deformities on undercorrection or overcorrection after OWHTO is unclear. This study was performed to evaluate whether femoral and tibial deformities affect postoperative alignment after OWHTO.

Materials and Methods

1. Patients

This study was approved by our institutional review board, and informed consent was obtained from the patients in accordance with the laws and regulations of our country. The present study included 45 knees of 45 patients (13 men, 32 women) treated by OWHTO from February 2012 to June 2015. All surgeries were performed by one surgeon (H.S.). The clinical characteristics assessed in this study were age at presentation, sex, body mass index, affected side, and Kellgren–Lawrence grade (Table 1). The severity of osteoarthritis was scored according to the Kellgren–Lawrence grade (0: none, I: doubtful, II: minimal, III: moderate, IV: severe)[15]. All patients had symptomatic medial unicompartmental varus osteoarthritis or medial local cartilage damage. The exclusion criteria were severe osteoarthritis of the knee and hip (Kellgren–Lawrence grade >III) and significant rotational malpositioning on radiographs.

2. Radiographic measurements

All patients routinely underwent bilateral standing anteroposterior radiographs preoperatively; 3, 6, and 12 months postoperatively; and annually thereafter. These radiographs were taken with the lower extremities in a neutral position so that the patella faced forward. Six radiographic parameters were measured preoperatively and 12 months postoperatively: the percentile of the mechanical axis on the tibial plateau (%MA) (Fig. 1A), the mechanical lateral distal femoral angle (mLDFA) (Fig. 1B), the BFS (Fig. 1C), the FNFSA (Fig. 1D), and the preoperative and postoperative mechanical medial proximal tibial angle (mMPTA) (Fig. 1E). The mechanical axis was drawn from the central point of the femoral head to the central point of the articular surface of the talus. The %MA was defined as the proportion of the medial edge of the tibia to the point at which the mechanical axis passed through the articular surface of the tibia in the total tibial articular width (Fig. 1A). The mLDFA was defined as the lateral angle between the central point of the femoral head to the central point of the articular surface of the femur and the tangent of the distal femoral joint line (Fig. 1B). The BFS was defined as the angle between the central lines of the distal and proximal diaphysis of the femur, expressed as the degrees of medial (−) or lateral (+) bowing deviation from 0° (Fig. 1C).

The FNFSA was defined as the angle between the line from the center of the femoral head to the midpoint of the narrowest portion of the femoral neck and the proximal femoral shaft (Fig. 1D). Finally, the mMPTA was defined as the medial angle between the line from the center of the articular aspect of the talus to the center of the tibial plateau and the tangent of the tibial joint line (Fig. 1E). All measurements were based on previous studies[14)16)] and performed using a standardized picture archiving and communication system[17)].

The postoperative %MA was divided into three groups according to a previous report[7)10)]: Group I (undercorrection; %MA of <56%), Group II (acceptable correction; %MA of 57%–67%), and Group III (overcorrection; %MA of >67%).

3. Surgical technique and postoperative rehabilitation

Arthroscopy was conducted before osteotomy to evaluate the medial and lateral cartilage. OWHTO was performed in a biplanar fashion according to a previously reported method[7)18)19)]. Biplanar frontal and transverse cutting was performed, and the osteotomy site was then opened using an opener (Olympus Terumo Biomaterials Corp., Tokyo, Japan) until the target %MA was reached. The new %MA was set to the 62% position, which had been determined through preoperative planning (Fig. 2). Intraoperative confirmation of the %MA was performed with a cable extending over the whole limb from the center of the femoral head to the center of the talus under fluoroscopy[7)20)]. Two wedge-shaped beta-tricalcium phosphate blocks (OSferion60; Olympus Terumo Biomaterials Corp.) of appropriate size were placed into the gap. The osteotomy was fixed with a medial locking plate (Tomofix; DePuy Synthes, Warsaw, IN, USA or TriS plate; Olympus Terumo Biomaterials Corp.).

Active and passive postoperative range of motion exercises were initiated on the second postoperative day. One-half weight-bearing with a crutch typically began at 2 weeks postoperatively. Full weight-bearing was allowed at 4 weeks postoperatively.

4. Statistical analysis

Statistical analyses were performed using SPSS ver. 20.0 for Windows (IBM Japan Ltd., Tokyo, Japan) with statistical significance defined as $p < 0.05$. All continuous data are expressed as mean ± standard deviation. The Shapiro–Wilk test was used to ensure normality of the data distribution. The patients' demographic characteristics data among the three groups were analyze by one-way analysis of variance or Kruskal-Wallis test for continuous variables and Chi-squared tests or Fisher exact tests for categorical variables. One-way analysis of variance was performed to compare differences in the mean mLDFA, BFS, FNFSA, and preoperative and postoperative mMPTA among the three groups, and statistically significant differences were assessed using the post hoc Tukey test to determine which two of the three groups differed significantly. Pearson's product-moment correlation coefficient was used to identify relationships between the mLDFA and BFS or FNFSA. Univariable and multivariable logistic analyses were performed to identify the factors associated with undercorrection and overcorrection. The cut-off values of factors associated with undercorrection and overcorrection were measured by the receiver operating characteristics (ROC) method with the corresponding sensitivity, specificity, and area under the curve (AUC).

Results

Twenty-three patients (51%) showed acceptable correction (Group II), whereas undercorrection (Group I) and overcorrection (Group III) was found in 12 (27%) and 10 patients (22%), respectively. The statistical results of patients' demographic characteristics among the three groups are shown Table 2. There was no significant difference in the patients' demographic characteristics data. The one-way analysis of variance results are shown Table 3. The mean mLDFA in Groups I, II, and III was 90.0° ± 2.4°, 87.3° ± 1.3°, and 88.0° ± 2.1°, respectively (Fig. 3A). There was a statistically significant difference between Groups I and II or III ($p < 0.01$) (Table 3). The mean BFS in Groups I, II, and III was 3.3° ± 2.3°, −0.3° ± 2.0°, and −1.5° ± 2.3°, respectively (Fig. 3B). There was a statistically significant difference between Groups I and II or III ($p < 0.01$) (Table 3). The mean FNFSA in Groups I, II, and III was 126.5° ± 5.4°, 126.8° ± 3.9°, and 126.7° ± 3.7°, respectively (Fig. 3C). There was no statistically significant difference among the three groups (Table 3). The mean preoperative mMPTA in Groups I, II, and III was 83.9° ± 1.0°, 86.1° ± 2.1°, and 86.4° ± 1.0°, respectively (Fig. 3D). There was a statistically significant difference between Groups I and II or III ($p < 0.05$) (Table 3). The mean postoperative mMPTA in Groups I, II, and III was 92.3° ± 2.8°, 92.1° ± 1.2°, and 94.9° ± 1.6°, respectively (Fig. 3E). There was a statistically significant difference between Groups III and I or II ($p < 0.01$) (Table 3). A positive correlation was found between mLDFA and BFS ($r = 0.47$, $p < 0.01$), and a negative correlation was found between mLDFA and FNFSA ($r = -0.42$, $p < 0.01$). Univariable analyses comparing undercorrection (Group I) and acceptable correction (Group II) identified mLDFA [odds ratio (OR), 7.35; 95% confidence interval (95% CI), 1.84–29.41], BFS (OR, 9.41; 95% CI, 1.97–44.82), and preoperative mMPTA (OR, 0.15; 95% CI, 0.04–0.64) as significant factors associated with undercorrection (Table 4). Moreover, the multivariable analysis confirmed mLDFA (OR, 15.60; 95% CI, 2.01–120.97) and BFS (OR, 11.60; 95% CI, 1.32–33.3) as significant factors associated with undercorrection (Table 4). Univariable analyses comparing overcorrection and acceptable correction identified postoperative mMPTA (OR, 22.72; 95% CI, 2.21–234.05) as a significant factor associated with overcorrection (Table 5). Moreover, the multivariable analysis confirmed postoperative mMPTA (OR, 88; 95% CI, 1.66–4665.33) as a significant factor associated with overcorrection (Table 5). The cut-off values for mLDFA and BFS as calculated by the ROC method were 90.0° (sensitivity, 50.0%; specificity, 100%; AUC, 0.85) (Fig. 4A) and 0.35° (sensitivity, 91.7%; specificity, 72.7%; AUC, 0.89) (Fig. 4B), respectively.

Discussion

The most important finding of the present study is that mLDFA and BFS affected the lower limb alignment after OWHTO.

With respect to undercorrection, comparison of the undercorrection group (Group I) and the acceptable correction group (Group II) showed that mLDFA and BFS were greater in Group I than in Group II despite the fact that the mean postoperative mMPTA was similar between the two groups (Table 3). In a previous study examining the factors of undercorrection after OWHTO in 37 knees, the authors considered that undercorrection was caused by varus inclination of the distal femoral line and a greater horizontal obliquity of the tibial joint line[11]. The BFS is greater in Japanese than in Western populations[21]. Although a relationship between the BFS and the postoperative clinical outcome after closed wedge high tibial osteotomy has been reported[22], no study has examined the relationship between BFS and %MA after OWHTO. The present study suggests that the mLDFA is positively correlated with BFS and that these two factors significantly influence undercorrection rather than preoperative mMPTA. Our results suggest that inclination of the distal femur exceeding 90.0° and lateral femoral bowing exceeding 0.35° may induce undercorrection.

Several factors associated with overcorrection have been proposed, including a greater obliquity of the postoperative mMPTA, laxity among individual patients, and differences in soft balance tension due to measuring the %MA preoperatively and intraoperatively[11][23]. In our study, the postoperative mMPTA in the overcorrection group (Group III) was significantly greater than that in the acceptable group (Group II). Moreover, our logistic analysis revealed that the postoperative mMPTA significantly influenced overcorrection. This result suggests that excessive surgical correction might have been performed without consideration of joint laxity.

The present study suggests that it is important to consider the combination of femoral osteotomy to obtain acceptable correction in patients with femoral deformity exceeding

90.0° in the inclination of the distal femur and exceeding 0.35° in lateral femoral bowing.

There are several limitations in this study. First, the patient cohort was small. Sample size analyses for one-way analysis of variance using G*Power 3.1.9.4 (Franz paul, Kiel, Germany) were performed under the effect size calculated from the first 25 cases. Effective statistical power of 80% (α =0.05) was calculated for five parameters of axial lower limb alignment. Each required total sample size of mLDFA, BFS, FNFSA, preoperative mMPTA, and postoperative mMPTA were 51, 21, 1770, 72, and 42 cases, respectively. Thus, our statistical power of mLDFA and preoperative mMPTA were insufficient. However, the operation was performed in combination with distal femoral osteotomy for patients with a greater inclination of the femoral joint beginning in 2016. Thus, we consider that inclusion of patients after 2016 would have led to selection bias and prevented proper assessment of the influence of the femur. Second, a radiological assessment after OWHTO was only performed at 12 months. Thus, we did not investigate the effect of temporal changes in the osteotomy site on the %MA. Third, we were unable to assess the soft tissue around the knee, including the ligaments or meniscus that may affect postoperative alignment. Future studies are required to investigate the effects of these factors on alignment.

In conclusion, unacceptable correction after OWHTO was associated with femoral deformities. These findings suggest that femoral deformities must be considered to achieve acceptable alignment after osteotomy around the knee. To prevent postoperative undercorrection, if the preoperative mLDFA exceeds 90.0° and the BFS exceeds 0.35°, the patient may have not only an indication for OWHTO but also an indication for double level osteotomy.

Acknowledgment

We thank Angela Morben, DVM, ELS, for editing a draft of this manuscript.

Conflict of interest

The authors declare no conflict of interest.

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Legends for Figures

Fig. 1: Evaluation of leg alignment. The (A) percentage of the mechanical axis on the tibial plateau (%MA), (B) mechanical lateral distal femoral angle (mLDFA), (C) lateral bowing angle of the femoral shaft (BFS), (D) femoral neck–femoral shaft angle (FNFSA), and (E) mechanical medial proximal tibial angle (mMPTA) were measured to evaluate leg alignment.

Fig. 2: Preoperative planning of corrective angle. (A) The mechanical axis of the lower limb is drawn as a broken line, and the new mechanical axis is drawn so that the percentage of the mechanical axis on the tibial plateau is 62% (Line I). (B) Partial enlarged view of the knee joint in Fig. 2A. (C) Line II connects the osteotomy hinge point (Point H) with the center of the ankle joint. Line III connects the hinge point (Point H) with the arc intersection with Line I. The angle of correction is formed between Lines II and III.

Fig. 3: Box plot showing the (A) mechanical lateral distal femoral angle (mLDFA), (B) lateral bowing angle of the femoral shaft (BFS), (C) femoral neck–femoral shaft angle (FNFSA), (D) preoperative mechanical medial proximal tibial angle (pre-mMPTA), and

(E) postoperative mechanical medial proximal tibial angle (post-mMPTA) in the three groups. *$p < 0.05$, **$p < 0.01$ (one-way analysis of variance and Tukey–Kramer test).

Fig. 4: Receiver operating characteristic (ROC) curve analysis for the mechanical lateral distal femoral angle (mLDFA) and lateral bowing angle of the femoral shaft (BFS). (A) ROC curve showing the mLDFA cut-off value (arrow) that discriminates undercorrection from acceptable correction and overcorrection. (B) ROC curve showing the BFS cut-off value (arrow) that discriminates undercorrection from acceptable correction and overcorrection. AUC: area under the curve.

Fig. 1

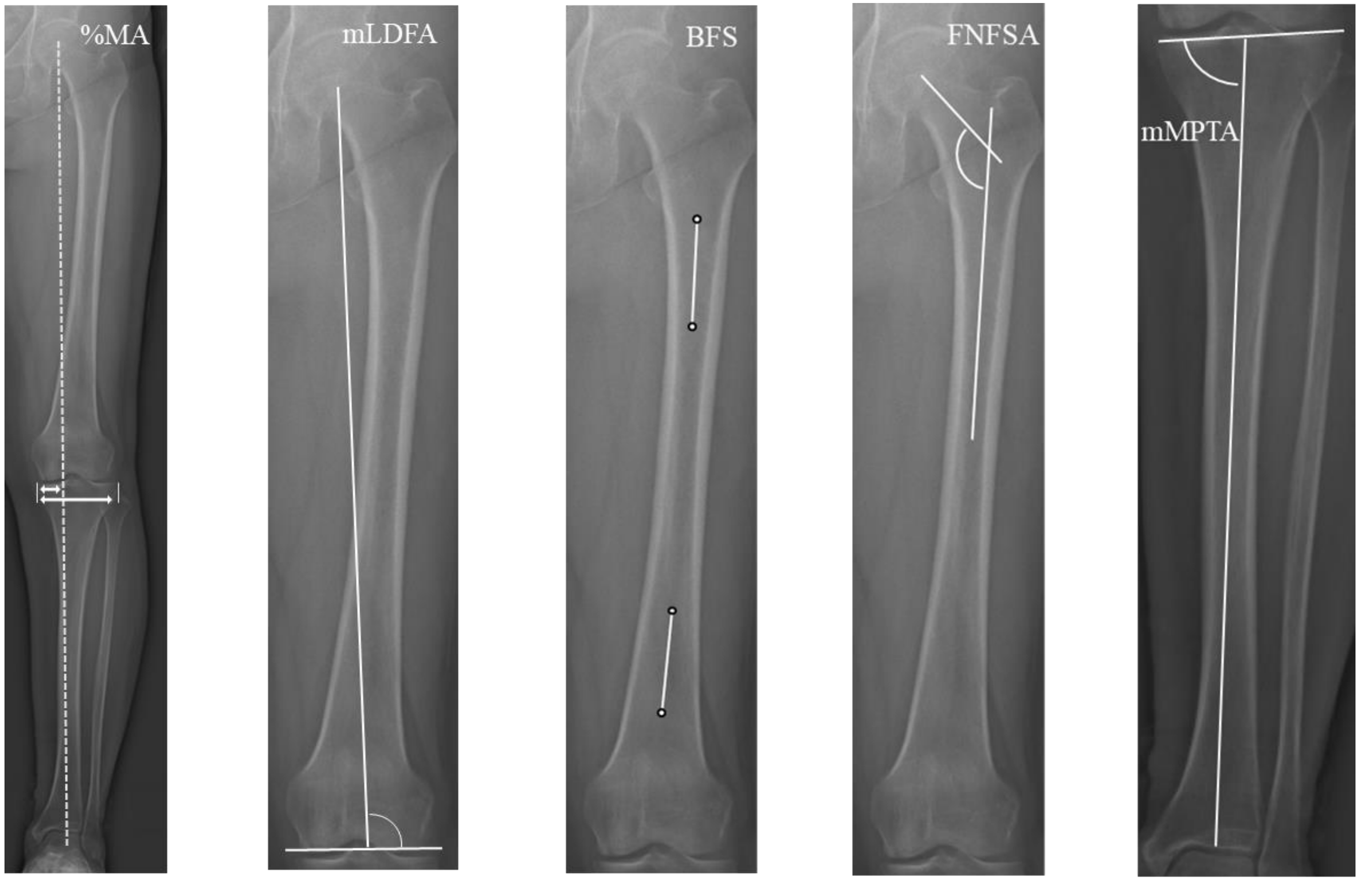

Fig. 1A Fig. 1B Fig. 1C Fig. 1D Fig. 1E

Fig. 2

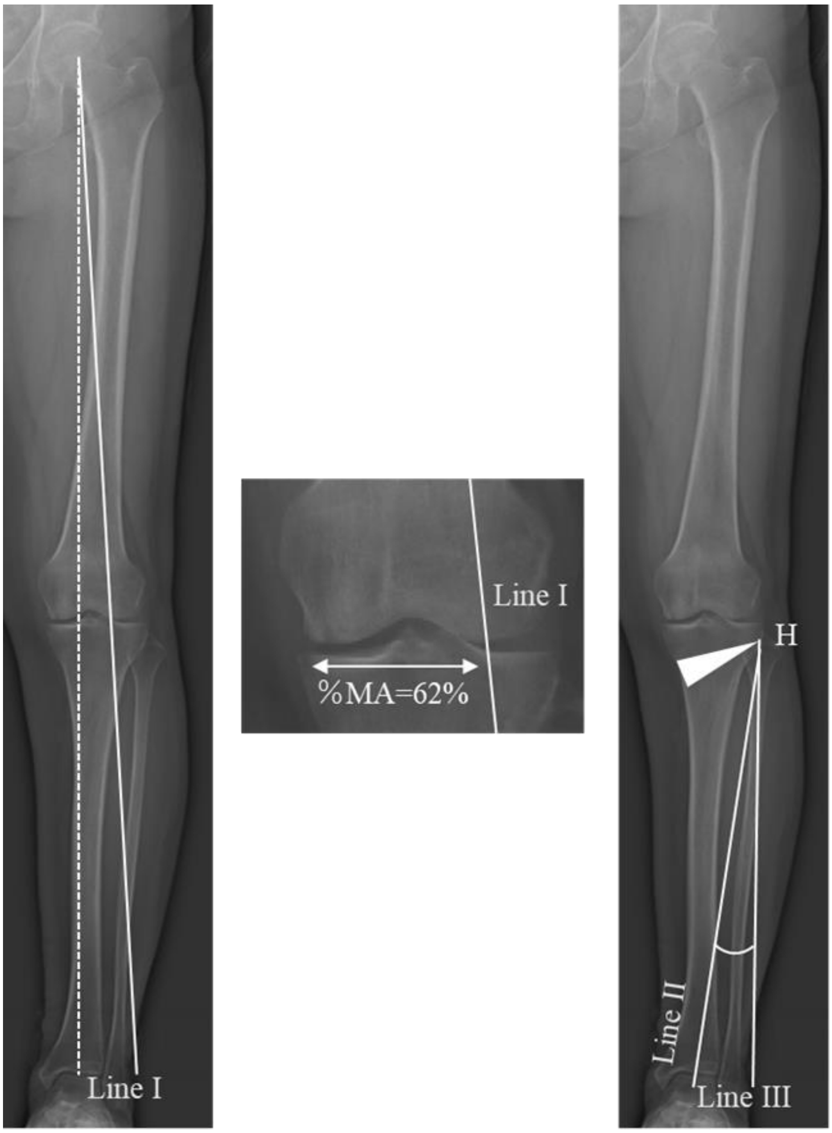

Fig. 2A

Fig. 2B

Fig. 2C

Fig. 3

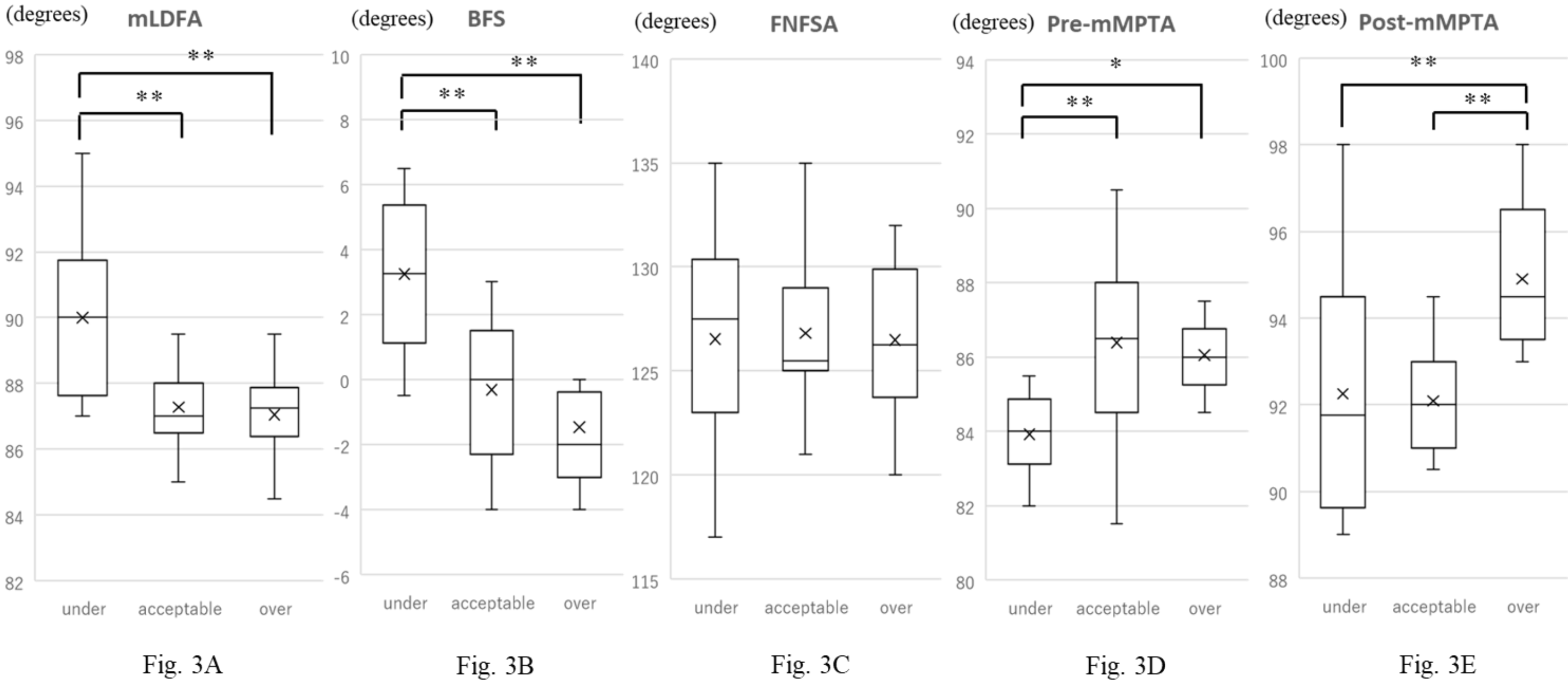
(degrees)
mLDFA
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Fig. 4

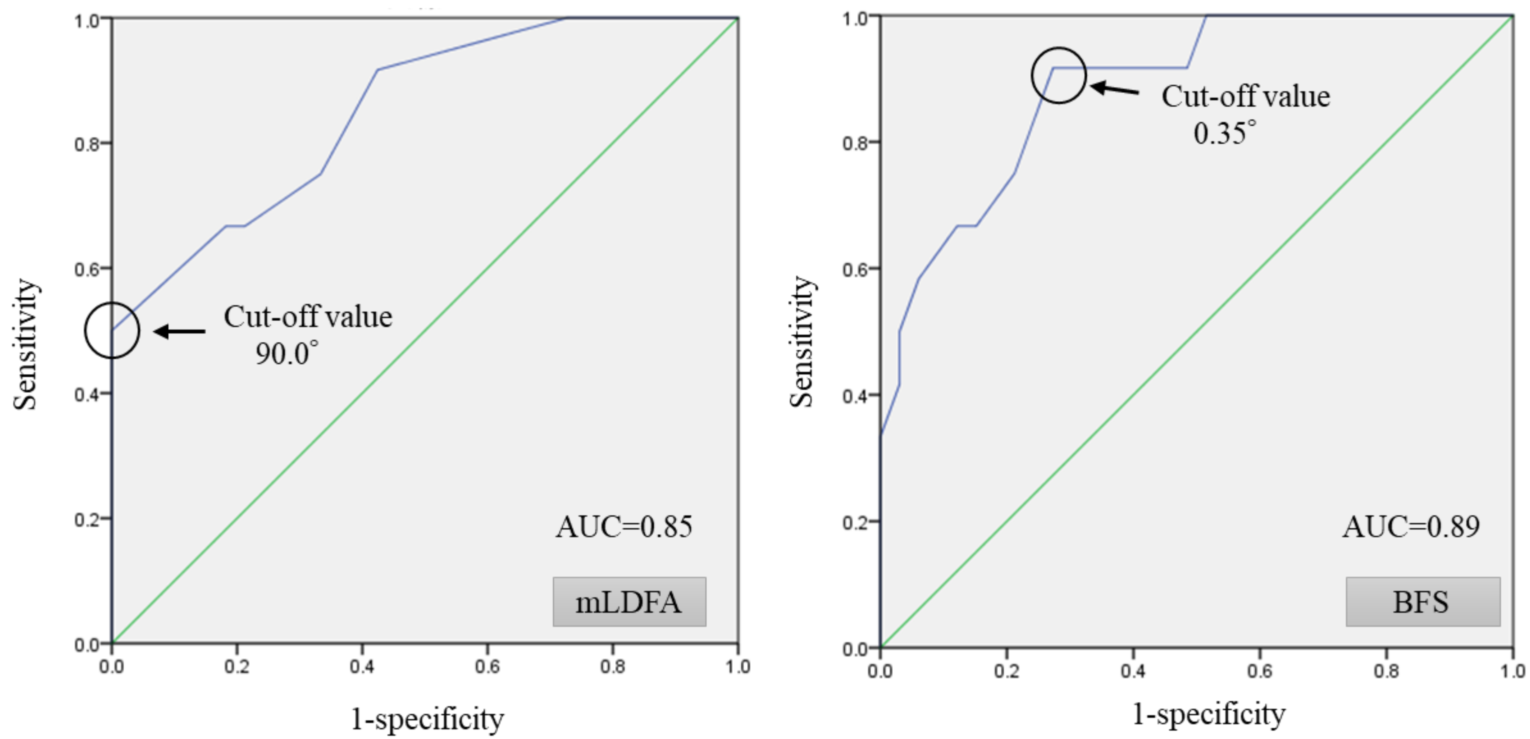

Fig. 4A

Fig. 4B

Table 1. Patients' demographic characteristics (n = 45).

Patient characteristics			
Age, years	68.1 ± 7.8	Range: 53–82	
Sex	Male: 14	Female: 31	
Body mass index, kg/m^2	24.4 ± 3.3	Range: 17.7–32.9	
Affected side	Right: 16	Left: 29	
K-L grade	Grade I: 0	Grade II: 36	Grade III: 9

Data are presented as mean ± standard deviation or number of patients unless otherwise indicated.

K-L grade: Kellgren–Lawrence grade

Table 2. Patients' demographic characteristics in three groups.

Patient characteristics	Group I (n=12)	Group II (n=23)	Group III (n=10)	p value
Age, years	71.2 ± 8.1	66.5 ± 8.3	68.1 ± 8.3	0.32
Sex, male/female	3/9	9/14	2/8	0.53
Body mass index, kg/m^2	25.5 ± 3.0	24.2 ± 3.4	23.9 ± 3.0	0.44
Affected side (Right/Left)	4/8	11/12	1/9	0.10
K-L grade (I/II/III)	(0/10/2)	(0/18/5)	(0/8/2)	1

Data are presented as mean ± standard deviation or number of patients unless otherwise indicated.

A one-way analysis of variance, Kruskal-Wallis test, chi-squared test and Fishier exact test were used

K-L grade: Kellgren–Lawrence grade

Table 3. Differences in mean mLDFA, BFS, FNFSA, pre-mMPTA, and post-mMPTA among the groups as determined by one-way analysis of variance.

Dependent variable	Comparison	Mean difference	SE	95% CI	p
mLDFA	Group I vs. II	2.72	0.62	1.22 to 4.22	<0.01
	Group I vs. III	2.95	0.74	1.15 to 4.75	<0.01
	Group II vs. III	0.23	0.66	-1.36 to 1.83	0.93
BFS	Group I vs. II	3.45	0.75	1.64 to 5.27	<0.01
	Group I vs. III	4.60	0.89	2.44 to 6.77	<0.01
	Group II vs. III	1.15	0.77	-0.72 to 3.03	0.30
FNFSA	Group I vs. II	-0.26	1.53	-4.00 to 3.48	0.98
	Group I vs. III	0.42	1.85	-4.45 to 4.54	1.00
	Group II vs. III	0.30	1.64	-3.63 to 4.28	0.98
Pre-mMPTA	Group I vs. II	-2.47	0.61	-3.97 to -0.98	<0.01
	Group I vs. III	-2.13	0.74	-3.92 to -0.34	0.02
	Group II vs. III	0.34	0.65	-1.24 to 1.93	0.86
Post-mMPTA	Group I vs. II	0.16	0.65	-1.41 to 1.73	0.97
	Group I vs. III	-2.65	0.78	-4.54 to -0.76	<0.01
	Group II vs. III	-2.81	0.69	-4.48 to -1.15	<0.01

SE: standard error, CI: confidence interval, mLDFA: mechanical lateral distal femoral angle, BFS: lateral bowing angle of the femoral shaft, FNFSA: femoral neck–femoral shaft angle, Pre-mMPTA and Post-mMPTA: preoperative and postoperative mechanical medial proximal tibial angle.

Table 4. Logistic analysis of influence of undercorrection.

Dependent variable	Univariable			Multivariable**		
	OR*	95% CI	p value	OR*	95% CI	p value
mLDFA	7.35	1.84 to 29.41	0.005	15.60	2.01 to 120.97	0.01
BFS	9.41	1.97 to 44.82	0.005	11.60	1.32 to 33.3	0.02
FNFSA	0.93	0.46 to 1.86	0.83	0.94	0.42 to 2.04	0.85
Pre-mMPTA	0.15	0.04 to 0.64	0.01	0.01	0.00 to 1.29	0.06
Post-mMPTA	1.10	0.55 to 2.18	0.79	1.08	0.51 to 2.28	0.85

CI: confidence interval, mLDFA: mechanical lateral distal femoral angle, BFS: lateral bowing angle of the femoral shaft, FNFSA: femoral neck–femoral shaft angle, Pre-mMPTA and Post-mMPTA: preoperative and postoperative mechanical medial proximal tibial angle.
*Per increase of 1 standard deviation (2.12 for mLDFA, 2.70 for BFS, 4.33 for FNFTA, 2.18 for pre-mMPTA, 1.81 for post-mMPTA).
**Adjusted for age, sex, body mass index, and Kellgren–Lawrence grade.

Table 5. Logistic analysis of influence of overcorrection.

Dependent variable	Univariable			Multivariable**		
	OR*	95% CI	p value	OR*	95% CI	p value
mLDFA	0.93	0.43 to 1.98	0.84	0.92	0.41 to 2.08	0.85
BFS	0.54	0.23 to 1.28	0.16	0.51	0.20 to 1.30	0.16
FNFSA	0.93	0.43 to 1.98	0.84	0.90	0.40 to 2.04	0.90
Pre-mMPTA	0.84	0.39 to 1.81	0.66	0.62	0.23 to 1.67	0.35
Post-mMPTA	22.72	2.21 to 234.04	0.009	88.11	1.66 to 4665.33	0.03

CI: confidence interval, mLDFA: mechanical lateral distal femoral angle, BFS: lateral bowing angle of the femoral shaft, FNFSA: femoral neck–femoral shaft angle, Pre-mMPTA and Post-mMPTA: preoperative and postoperative mechanical medial proximal tibial angle.

*Per increase of 1 standard deviation (1.36 for mLDFA, 2.18 for BFS, 3.75 for FNFTA, 1.85 for pre-mMPTA, 1.81 for post-mMPTA).

**Adjusted for age, sex, body mass index, and Kellgren–Lawrence grade.